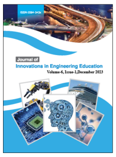

Journal of Innovations in Engineering Education
JIEE 2023, Vol. 6, Issue 1.

https://doi.org/10.3126/jiee.v6i1.59091

THAPATHALI CAMPUS
Institute of Engineering
Tribhuvan University

Landfill Leachate: Review of various treatment approaches

Lokesh Sapkota[a], Dr. Rajendra Joshi[b], Dr. Anish Ghimire[a], Lakisha Shrestha[a], Sophie Shrees[a] and Dr. Bikash Adhikari[a,*]

[a]*Kathmandu University, School of Science, Environmental Engineering Program, Dhulikhel, Kavre, Nepal*
[b]*Kathmandu University, School of Science, Department of Pharmacy, Dhulikhel, Kavre, Nepal*

ARTICLE INFO

Article history:

Received 5 Oct 2023
Revised in 1 Dec 2023
Accepted 9 Dec 2023

Keywords:

Landfill Leachate
Leachate Treatment
Anaerobic Ammonium Oxidation
Coagulation and Flocculation
Membrane Filtration

Abstract

The burning issue of Solid waste management has become more prevalent in municipals of emerging nations as a combined effort of population growth, economic expansion, and rising living standards. In Nepal, 48.6% of municipalities choose to pile rubbish in landfills, while the remaining municipalities choose to burn their waste or pile it up along rivers. Leachate, a hazardous pollutant that harms soil, ground and surface water, human health, hygiene, and aquatic life, is a liquid produced from the bottom of solid waste disposal facilities.Leachate is treated via three processes: physical, chemical, and biological in landfills. The goal of the current paper is to review the leachate treatment options currently on the market. Instead of adopting a single treatment procedure, with physical and chemical process in combination of biological treatment has shown the effective performance. The onsite leachate solution is given an appropriate low cost option via land treatment of the landfill leachate. Cover soil can be thought of as a primary component of landfill operating strategy for separating trash from the environment and employed as a medium for the reduction of organic loads and specific toxic metals in leachate. This paper will be helpful in examining the many alternatives for treating landfill leachate.

1. Introduction

Rapid Urbanization and technological advancement have increased population product consumption, which has multiplied the amount of wastes dumped annually in the landfills[1]. Solid Waste segregation is still not at a typical practise in underdeveloped nations, landfilling is an inescapable option[2]. Landfills collect around 95% of the waste generated worldwide[3] and the rest are recycled, reused, or reduced. The waste in the landfills goes through several biological and physiochemical changes producing leachate that is highly contaminated [4]. Uncontrolled disposal of solid waste and the leachate that results from it can lead to pollution, various environmental dangers and health problems. The leachate generated has a greater capability of polluting groundwater, surface water, and soil making its treatment a challenge[5]. The dissolved organic matter in the leachate can alter the transport, stability, behaviour, and bioavailability of heavy metals as well as the coagulation and flocculation process. It can also affect microbial performance through interactions with orrganic pollutants and cause fouling by disrupting the membrane[6]. Leachate treatment, which may involve physical, chemical, or biological treatment, is well explained in this article. Recent research has revealed that treating landfill leachate performs better when biological and physiochemical treatment are combined.Leachate from landfills will also be treated on-site using land-based methods, which will help reduce costs. Better technology is required for the proper management and treatment of landfill leachate as well as for the successful treatment of landfill leachate.

2. Characteristics of landfill Leachate

Leachate from landfills contains a wide range of heavy metals, total dissolved solids, pathogens, nutrients, as well as organic and inorganic compounds, among other contaminants, all of which are very dangerous.

*Corresponding author:
bikashadhikari@ku.edu.np (Dr.B. Adhikari)

Table 1: Characteristics of landfill leachate

Parameter	Early	Medium-term	Old
Landfill useful life (years)	< 5	$5 - 10$	> 10
pH	$6.5 - 7.5(7.0)$	$7.0 - 8.0(7.5)$	$7.5 - 8.5(8)$
COD (mg/L)	$10 - 30(15)$	$3 - 10(5)$	$< 3(2)$
BOD/COD	$0.5 - 0.7(0.6)$	$0.3 - 0.5(0.4)$	$< 0.3(0.2)$
NH_4^+-N (mg/L)	$500 - 1000(700)$	$800 - 2000(1000)$	$1000 - 3000(2000)$
COD/NH_4^+-N	$5 - 10(6)$	$3 - 4(3)$	$< 3(1.5)$

Leachate's composition varies according to the types of waste produced, the lifespan of landfills, their architecture, the climate, ecology, and management techniques. The characteristic of landfill leachate with various parameters is presented in Table 1 at different time[7]. The leachate's early stage, which lasts for less than five years, is acidic, has a low Ammonical nitrogen concentration and a high COD concentration as well as a high BOD/COD ratio. In the mature (medium-term) leachate, the pH values are slightly high than in the early phase within the range of 7-8 in the development of 5 to 10 years of period. In this phase, the COD, BOD/COD ratio, and COD/ $NH_4{}^+$-N ratio of the leachate are less than in the previous stage, and $NH_4{}^+$-N in the 800-2000 mg/L range. The growth of leachate after 10 years showed the COD (g/L) and COD/ $NH_4{}^+$-N ratio values are below 3, and BOD/COD ratio with less than 0.3. These types of leachate are considered as old (methanogenic) and the pH is relatively high. Therefore, knowledge of leachate's characteristics is essential for both excellent treatment and little impact on the landfills[7].

3. Treatment methods of landfill Leachate

Leachate from landfills must be treated according to its specific properties. Different treatments are offered based on the leachate's composition. Physical, chemical and biological treatment are included in this review paper.

3.1. Biological treatment

Microorganisms that are crucial to the biodegradation of organic waste assist in eliminating the contaminants from landfill leachate during the biological treatment process. The biological procedure also eliminates leachate with a significant amount of BOD[8]. Treating the landfill leachate through a biological process can be done by following different processes like aerobic, anaerobic, nitrification/denitrification, the ANAMMOX process.

3.1.1 Aerobic treatment process

The organic compounds contained in the leachate are broken down by microorganisms in the aerobic system when oxygen is present. An activated sludge method, a rotating biological contactor, a sequence batch reactor (SBR), and Anoxic/oxic (A/O) can all be used to remediate landfill leachate.

Activated sludge is one of the commonly used practices for the treatment of wastewater. The organic matter is converted into CO2, H2O, and minerals by microorganisms through aerobic media[9]. Sequence batch reactor (SBR) is widely used for leachate treatment in activated sludge systems. This reactor has operational flexibility, and control possibilities and provides excellent processes[10]. It works on fill and draw principles and has equalization, treatment, and sedimentation in the same reactor[11]. High nitrogen loading rates shows the ammonium removal, whereas only low nitrogen loading rates resulted in satisfactory ammonium removal.[12] The study presented that only 12% of COD was removed, but 100% of $NH_4{}^+$-N was reduced using a sequencing batch reactor in aerobic-activated sludge[13]. Another study showed the high-efficiency treatment using combined SBR and RO system [14]. The SBR treated BOD, Fe, Cl- and TOC 64%, 29%, 0.2%, and -5.3% respectively for young leachate.) The operational flexibility, high biomass retention, and resistance to shock load SBR is widely applicable in landfill leachate and wastewater treatment[15].

Another method for treating leachate Membrane Bioreactor (MBR). MBR has the benefit to eliminate suspended solids and organic pollutants. The results with MBR showed better performance with 95% removal of

BOD, TN, and NH_3 and improvement in SBR efficiency [16]. MBR employed at SRT for 144 days and obtained removal rates of 98% for BOD, 96% for ammonium, likewise for COD 75% was obtained. A study by was conducted on solid waste leachate which was operated on two-stage MBR with sludge recirculation achieved >97-99% organic carbon and >94% nitrogen removal. The reduction of biochemical methane of leachate during MBR treatment was observed with a 73.5% deduction of CH4 emission[18].

When treating landfill leachate, the A/O process has the potential to remove strong nitrogen while reducing the rate of COD. In order to remove contaminants from landfill leachate, the study compbined a two stage anoxic/oxic process with membrane bioreactor (MBR) [19]. The value of R under 150% achieved better results for the removal of chemical oxygen demand (COD) at 85.6%, ammonium (NH_4^+-N) at 99.3%, and total nitrogen (TN) at 80.7%. With a removal capability of 788 g/d for COD and 11.74 g/d for TN, the second stage A/O process had the maximum capacity. The possibility of reducing N20 emissions and treating organic matter contained in landfill leachate was postulated using a two-stage A/O process[20]. The integrated anoxic/aerobic process with sludge circulation demonstrated that lower molecular weight acid, building blocks, and lower molecular weight neutrals were eliminated from the system as a result of denitrification in an anoxic unit. With an influent COD/N ratio it was treated up to 84% and for the incoming nitrogen load overall 2.8 ± 0.5% of N_2O emission was purified. Rotating biological contactor (RBC) is a biological treatment frequently used for the nitrification and denitrification and biodegradation of organic matter[21]. The biological system for treating landfill leachate consists of an anoxic RBC with four aeration tanks and gradient aeration [22]. The system eliminated COD, and RBC is where the majority of the denitrification process took place, resulting in primary nitrification.

3.1.2 Anaerobic treatment process

Anaerobic treatment when there is no oxygen converts organic matter into biogas which mostly consists of CO_2 and CH_4 as well as biological sludge in lesser content[23]. It is a more cost-effective process and leachate treatment requires low maintenance. This treatment method is considered an eco-friendly method as biodegradation of organic matter carried out by microorganisms reduces waste as well as the energy consumption in removing pollutants is less. The method is sensitive to temperature, pH, nitrogen loading, carbon source, DO, and other elements. With the change in these parameters, huge differences can be observed therefore, optimal conditions should be maintained. Organic and inorganic contaminants, as well as heavy metals like arsenic, mercury, nickel and copper, are all present in landfill leachate. Another drawback is that is takes a long time to provide an effective result and might not be appropriate for inorganic pollution or leachate that contains a lot of toxic metals. The anaerobic treatment performs better than the aerobic treatment for landfill leachate in the biological treatment process due to the high COD concentration and high COD/BOD ratio[23].The activated sludge process may require an

extended granular sludge blanket (EGSB) and an upflow anaerobic sludge blanket (UASB) for the cleansing of landfill leachate in an anaerobic system[4]. The study for fresh leachate the treatment was effective in which the USAB reactor removed 67% of soluble COD in fresh leachate [24]. Likewise, about 35% of soluble COD was eradicated from old leachate with decreasing efficiency. The study demonstrated fresh leachate purification at OLR 12.5 kg, and a COD of up to 82.4% was out of the system with reactor UASB. Presented the UASB reactor combined with carbon removal moving bed biofilm reactor (MBBR) and, ANITA Mox technique. The findings revealed that 93% of COD was removed and 70% of all inorganic nitrogen. An EGSB reactor can effectively handle NH3-N concentrations below 1500 mg/L as well as those with a high ammonia nitrogen concentration [25]. Significant biomass is accumulated inside the bioreactors of several anaerobic processes like EGSB, USAB, ABR, or AFBR [26].

3.1.3 Nitrification/Denitrification process

It is financially feasible to remove NH3-N from landfill leachate using nitrification. Ammonium is produced during the hydrolysis of organic nitrogen in wastewater to amino acids[27]. There are two phases in the nitrification process. Ammonium-oxidizing bacteria first convert the ammonia to nitrite. In the following phase, nitrifiers or nitrite-oxidizing bacteria convert the nitrite to nitrate.The process of turning ammonium into nitrate is known as nitrification. With the aid of microorganisms known as heterotrophs, nitrate is then transformed into N_2 during denitrification under anoxic circumstances.

3.1.4 Anaerobic Ammonium oxidation (Anammox)

The treatment of nitrogen-rich wastewater by Anaerobic Ammonia Oxidation (Anammox), which is entirely based on the autotrophic technique. In this procedure, nitrite serves as an electon acceptor as the ammonium is oxidized to dinitrogen gas in anaerobic conditions. Only a portion of the ammonium needs to be converted to nitrite when the Anammox process is used in conjunction with an earlier nitrification phase. The remaining ammonium is then mixed with the nitrite to create dinitrogen gas. The bacteria such as Candidatus jettenia, Candidatus anammoxoglobus, Candidatus brocadia, Candidatus scalindua, Candidatus anammoximicrobium, and Candidatus kuenenia contributes to the anammox process[28]. According to the study, nitrogen was successfully and effectively extracted from old landfill leachate at a full scale landfill site using a combination of nitrification and denitrification with annammox in a sequence bed batch reactor[29]. Denitrogenation was carried out in the study using a partial-nitrification Anammox biofilm reactor (PNABR) in pre-anoxic, aerobic, and anoxic conditions[30]. This approach increased the nitrogen removal rate (NRR) and nitrogen removal efficiency (NRE) by 396.6 gN/(m^3.d) and 96.1%, respectively. Study of simultaneous ananmox, denitrification, and partial nitrification by [31] treated 98.7% of nitrogen at a loading rate of 0.23 $kg^{-3}d^{-1}$.

3.1.5 Constructed wetlands

Constructed wetlands are the natural process that filters and purifies the polluted water. It consists of substrate, sand, dirt or gravel, and plants to improve the water quality. The created wetlands are used to remediate landfill leachate can be environment-friendly and provide more sustainability [32]. The cost requirement for constructed wetlands is typically less, with low energy requirements. The zeliac and zeolite in a constructed wetland system to eradicate pollutants in landfill leachate [33]. The study removed phenol using an adsorption and biodegradation process [34]. Additionally, the vegetation in the wetland improved the usage of carbon sources by the bacteria breakdown BPA and 4-t-BP.

The study done by [18], claims that DEP, DBP, 2,6-DTBP, and BHT were eliminated as a result of biodegradation. Adsorption and development of iron organic that degraded in long term removed DEHP. According to the study by [35] oxygen and carbon can be modified in a variety of ways to carry out nitrogen removal processes including the nitrification-denitrification process, partial nitrification-denitrification process, and the anammox process. Another research demonstrated that based on parameters of the system, quantity, nature of organics, and toxicity content determine the degradation of contaminants [36].

3.2. Physical and chemical treatment

Physio-chemical is an important treatment carried out to treat and purify landfill leachate along with biological treatment. Coagulation, flocculation, adsorption, ion exchange, chemical precipitation, the AOP process, air stripping, and membrane filtration (reverse osmosis, ultrafiltration, and nanofiltration) are some of the physio-chemical approaches.

3.2.1 Coagulation and flocculation

One of the several physicochemical techniques typically used in the pre-treatment of old and stabilized landfill leachates before either a biological or another physicochemical procedure is coagulation-flocculation. This method has been used to successfully remove non-biodegradable organic compounds, suspended solids, colloidal particles, turbidity, colour, and heavy metals, depending on the cotntaminant and coagulant/flocculant type.

Turbidity was removed at a rate of 91.3% with a chitosan dosage of 0.6g/mL and a pH of 6, and at a rate of 85.2% with a pine bark dosage of 4g/mL and a pH of 7. The two complementary methods, coagulation-flocculation, and bio-sorption were assessed for their efficacy as low-cost, natural leachate treatment methods. According to the study, the ability of this sequence can remove lead, nickel, cadmium, zinc, and COD at rates of 43.24, 98.17, 67.45, 91.03, and 88.02%, respectively[37].

The study on use of ferric chloride for the removal of contaminants from landfill leachate [38] shows that the coagulation method reduced the color, and turbidity by 80%, and 90% respectively. The COD, and BOD5 by 50% and 99% respectively when 12 g Fe^{3+}/L was applied as the optimum dose.

According to the study, operating factors (such as coagulant dosage and pH) had an impact on how well poly aluminium chloride (PAC) treated landfill leachate.

3.2.2 Air stripping

In the air stripping technique, leachate or wastewater is exposed to air, as a result, an unwanted volatile substance present in the liquid is removed by gas and released into the atmosphere. Its processes take place in packed towers typically kept in counter current. According to the study, the air stripping procedure successfully removed 98% of ammonia nitrogen on average, running for 4 to 9 days and requiring 9 to 21 m^3 of air for each g of NH3-N removed. However, the system only had a 36% maximum removal effectiveness, indicating limited potential for COD removal [32]. The leachate stands out fro having a high proportion of organic material and a low proportion of biodegradable material. A lot of salts and ammonia are also present. Over 80% of the ammonia was removed during the air stripping pre-treatment, which enhanced the biodegradability and C/N ratio[39].

After 100 days of treatment, 97% of the COD was eliminated in an open horizontal flow reactor using the ammonia nitrogen stripping technique. They found that the efficiency of ammonia removal was directly connected with the applied surface laod and that the amount of organic matter in the effluent. The main advantage of this process is the ineffectiveness of organic matter degradation and the release of NH3 into the atmosphere, even though NH_3 can be an environmental hazard [40].

The methods of air stripping, followed by a series of CF and adsorption, were used to treat landfill leachate. Initial air stripping treatment was successful in removing upto 49.3% of COD, 74.1% of BOD_5, 96.3% of NH_3-N, and 84% of Hg during an ideal retention period of 36 hours. Following air stripping, the coagulation and flocculation response for COD was 55.3%, for BOD_5 it was 83.9%, for colour it was 91.8%, for Hg removal with COD it was 42.2% and for Hg removal after adsorption it was 56.1 and 89.2%, respectively. The study demonstrated air stripping's great performance as pretreatment method for ammonia removal from landfill leachate [41].

3.2.3 Adsorption

Adsorption is a different method for treating leachate. Activated carbon is one of the most prevalent adsorbents. Typically, carbonaceous or biomass materials like peat, wood bagasse, lignite, coal, coconut shells, and nutshells are used to make it. Benefits of this method include its ease of use, sensitivity to hazardous substances, capacity to remove a variety of pollutants, and simplicity of design[42].

Granular activated carbon (2.0g) is immersed in $KMnO_4$ solution (30mg/L) for six hours to create the modified activated carbon MAC [42]. MAC can remove 86% of Zinc and 99% of ammonia after 120 minutes of contact. This absorbent can remove zinc and ammonia with a 0.16mg/g Langmuir adsorption capacity. A study on the treatment of landfill leachate using both traditional and magnetic adsorbents done showed that the magnetic adsorbent is considerably more expensive that traditional adsorbents [43].

Additionally, the investigation revealed that the synthesis method had a greater environmental impact that the traditional adsorbents. A membrane method (MF, UF, fine-UF) along with powdered activated carbon (PAC) in adsorption to effectively remove organic compounds from stablised landfill leachate. When each membrane was paried with PAC, the treatment was more effective. The three membranes, PAC+MF and PAC+fine-UF stood out the most [44].

The procedure involved the use of powdered activated carobon (PAC) to adsorb colour, ammonical nitrogen (NH_3-N), and chemical oxygen demand (COD)[45]. For COD, colour, and NH_3-N, the effluent average efficiency was 66%, 87.63% and 25.89%, respectively. Following the regeneration of activated carbon, the removal efficiencies for COD, colour, and NH_3-N were determined to 85.74%, 92.65% and 59.53% respectively. According the the findings, the treatment of landfill leachate utilizing powdered activated carbon (PAC) through adsorption demonstrated the procedure' viability. Another study by [46] proved that adsorption by the Fenton process in removing contaminants is highly efficient. The study conducted with activated carbon both in granular and powdered form showed that granular activated carbon is better at treating COD and powdered activated carbon showed efficient results in removing color present in the leachate. The removal efficiency of COD and colour was obtained to be better than 99% using the Fenton-adsorption process, which could also remove 20.68 kg COD/kg carbon with an adsorption column created for this process

3.2.4 Ion exchange process

According to [47], examines the supercritical water oxidation (ScWO) process's intensification through ion exchange with zeolite. Inside a glass column, the zeolite (clinoptilolite) was employed in its original form. 90% of the ammoniacal nitrogen (NH_3-N), 100% of the nitrite ($N0_2$-N), 98% of the nitrate ($N0_2$-N), 81% of TOC, and 74% of COD were removed from the leachate by the combination of ScWO (600 C) and zeolite. This shows that this system is a promising alternative for leachate treatment. The final NH3-N and COD measurements, however, were just marginally above the thresholds (20 and 200 mg L1, respectively). Using electrochemical oxidation (EO) and electrodialysis (ED), ionic substances like phosphate and ammonium are removed. The concentrated ionic chemicals in the core compartment lower energy usage. The treatment was carried out in a batch recirculation with a constant current supply of 0.25A for 12 hours, resulting in the maximum chemical oxygen demand (COD) elimination efficiency of 86.2% (0.88 g $W^{-1}h^{-1}$). Ammonium, total phosphate, and chloride were removed while keeping the same conditions at 85% (0.44 g $W^{-1}h^{-1}$), 89% (0.08 g $W^{-1}h^{-1}$), and 83% (0.69 g $W^{-1}h^{-1}$), respectively.[48]

Scaling prevention by reducing the alkalinity of the landfill leachate nanofiltration concentration (LLNC). Ion exchange pre-treatment revealed that a moderately acidic cation-exchange resin outperformed a strongly acidic cation-exchange resin [49]. Compared to the raw LLNC up to 92.9%, the solid residue declined at alkalinity 0 mg/l. The study done by [50] examined the recovery of ammonium using cutting-edge ion exchanger loop stripping (ILS). The amount of liquid $NH4^+$ that was adsorbing to the clinoptilolite ranged from 13% to 61%. The new ion exchanger loop stripping (ILS) is workable for the recovery of $NH4^+$, according to the study.

3.2.5 Advanced Oxidation Process (AOP)

The leachate is more susceptible to further biological treatment, adsorption, or ion-exchange operations when AOP pre-treatment is applied [51]. The O_3/H_2O_2,

photo-Fenton, UV/H_2O_2, and O_3/UV are the frequently used AOP techniques for the pre-treatment of leachate. H_2O_2/COD ratio 1.42, current 2.2735 A, pH 2.9, and reaction time 30.3 min are the ideal conditions for advanced oxidation processes to remove COD, while S_2O_9/COD ratio 1.72, current 1.26 A, pH 5.0, and reaction time 34.8 min are the ideal parameters for EP procedures [52].
The study's results showed that the Electro-Fenton (EF) and Electro-Persulfate (EP) procedures, respectively, provided 60.8% COD and 90.7% colour removal efficiency.

A study used the peroxone (ozone/hydrogen peroxide) technique (O_3/H_2O_2), an O_3-based advanced oxidation process (AOP), to remove Diethyl phthalate (DEP) from synthetic leachate in a model that resembles solid-waste leachate from an open dump. It was reported that 99.9% of DEP was eliminated during 120 minutes of ozonation at 20 mg/L conducted in a semi-batch O_3 system with 4971 mg/L O_3 dosage transferred with 40 mg/L ofH_2O_2. [53]

While utilising less energy (3.10 KWhr/m^3), the hybrid photo-electro-Fenton process provided superior colour and COD removal efficiency of around 100% and 97%, respectively, than the photo and electro-Fenton methods alone [54]. Similar to this, a study using the Photo-Fenton method revealed that the procedure produced the best removal efficiency for COD and total PAHs, 84.43% and 92.54%, respectively, under an acidic pH of 6.5 [55] .

The COD and NH_3-N from the MSW leachate are treated using advanced oxidation processes (AOP) like ozonation, the peroxone process, and photolytic ozonation. For photolytic ozonation, optimal circumstances included pH 7, contact time of 60 minutes, and ozone dosages of 5 g/h. COD and NH_3-N received 72% and 80% of the treatment, respectively, and the ozonation process decreased their concentrations by 45% and 50%, respectively. The peroxone procedure with a concentration of H2O2 achieved the highest abatement, yielding 61% of COD and 59.7% of NH_3-N. The Response Surface Methodology (RSM)'s Central Composite Design (CCD) produced results by photolytic oxidation that were superior to those of the peroxone and ozonation processes [56].

3.2.6 Chemical precipitation

Chemical precipitation, bottom ash pretreatment, and bioremediation with microalgae are used to remediate landfill leachate by eliminating colour and turbidity. Chemical oxygen demand (COD) and colour had removal efficiencies of 74.3% and 98.5%, respectively, under the ideal pretreatment condition. In order to replace aggregate in mortar and cementitious formulations, the process-generated sludge was employed. Utilising this strategy has the advantages of low-cost cleanup and increased system sustainability. The elimination of COD, N, and P from the leachate inoculated with six distinct species of microalgae ranged from 18 to 62%, 63 to 71%, and 15 to 100%, respectively [57]. After removing sulphur compounds from high-strength industrial leachate using chemical precipitation and H_2O_2-driven catalytic oxidation, the leachate was suitable for the use of biological treatment [58].

In the study of [59], The solid trash at a landfill site was covered with the chemical precipitation sludge (CPS) produced by the chemical precipitation treatment of sanitary landfill leachate. According to the study, the CPS in landfills has no adverse effects and can be temporarily used as an environmentally benign sludge disposal option. Lower hydraulic conductivity was the result of increased leachate output, soil fine particle content, and CPS concentration. The pH parameter was most significantly changed by the values 7.03, 7.12, and 11.46 for 0, 5, and 10% CPS, respectively. The system achieved 5% biodegradability with no additional evidence of the leaching process.

In a study, six distinct pollutants from the polycyclic aromatic hydrocarbons (PAHs) family were removed from landfill leachate utilising chemical precipitation (CP), Fenton oxidation (FO), and ozone oxidation (OO). These pollutants included acenaphthylene, acenaphthene, fluorene, phenanthrene, and fluoranthene. With the exception of pyrene, the CP method had removal efficiency for PAHs that ranged from 6% to 40%. Micropollutants were removed with an efficiency of 70% using FO, however only around 55% of fluorene was successfully treated. Overall, the removal efficiency of PAHs from landfill leachate treated with CP, FO, and OO was between 80% and 100%.[60]

3.2.7 Membrane filtration

Membrane filtration is a widely used and advanced technology that separates particles from the liquid or gas phase in treating leachate and wastewater. For eliminating and decreasing various contaminants, including organic and inorganic debris, bacteria, and trace metals, membrane filtration is considered a very effective method[61]. Reverse Osmosis (RO), Nanofiltration, microfiltration, dynamic membranes (DMs), and ultrafiltration are the primary membrane techniques used in landfill leachate treatment[62]. Membranes have minimal overall energy consumption, are straightforward, and have great efficiency [63]. The membrane fouling, generation of waste from the membrane, damage of the membrane due to clogging, and the high cost of the membrane are the challenges faced while using the membrane.

Nano filtration

According to a study by [64], the synthetic leachate from the Blondo landfill may be extracted using nanofiltration membranes, where COD, TSS, and TDS were decreased by 96%, 100%, and 62%, respectively. The projected capital expenditures for a full-scale NF are MUS$ 0.772 [65]. A promising technique for eliminating contaminants, such as organic and inorganic particles, from landfill leachate that results from solid waste is nanofiltration (NF). Prior to biological treatment, the system addresses the BOD, COD, TDS, TSS, pH, hardness, and nutrients deficient in the methanogenic phase. Physiochemical treatment improves landfill leachate treatment in the beginning of the process, even though NF cleansed 60–70% of COD.

The combination treatment of coagulation-flocculation with lime and nanofiltration was utilised in the treatment procedure, according to the study by [66], and it demonstrated effective treatment for NH3-N. The percentages of eliminated chemical oxygen demand (COD), humic substance (HS), and total organic carbon (TOC) were 98%, 80%, and 94%, respectively.

Ultra filtration

The possibility of including UF as an additional enhanced stage in the biological treatment procedure. They showed that TSS, nitrate and phosphate, Al, and Zn were all removed by UF at rates of 100%, 98%, 95%, 100%, and 82%, respectively. However, the ultrafiltration porosity limits the membrane's ability to pass through large amounts of dissolved and suspended compounds. The use of electrospun polyacrylic acid (PAA)/polyallylamine hydrochloride (PAH)-laminated ultrafiltration (UF) membranes (PAA/PAH-UF) to remove heavy metals from landfill leachate. The PAA/PAH-UF modified membrane exhibits a greater 38-85% removal efficiency. Metal removal rates were increased by complexing Suwannee River Natural Organic Matter (SRNOM) functional groups with abundant functional groups from PAA/PAH fibre mats.

The removal rate of the metal ions rose by 30% in the presence of SRNOM compared to higher concentrations, which were only up to 20% at higher concentrations (50 and 100 mg/l), especially for Cu, Cd, and Pb [67] .

According to the study by, [68] assessed the efficacy of three ultrafiltration ceramic membranes with varied pore sizes (0.02, 0.05, and 0.01 m) in eliminating contaminants from leachate as a pretreatment. Transmembrane pressure (TMP) increases the retention of suspended solids (SS) and chemical oxygen demand (COD), and for circulation velocities of 0.5 m/s, the greatest values for COD were 85%, 77%, and 72%. Similar results were found for SS, which were 70.4%, 62%, and 55%, respectively. Despite treatment and an improvement over the conventional pretreatment, the pollutant content was remained high, according to the study. The pollution in the waste site has increased the number of microplastics produced.In a leachate treatment system including pretreatment, biotreatment, and advanced treatment, the study of [69] on the features and removal effectiveness of microplastics (MP) is discussed. After treatment, the MP that collected in the slugde may have an adverse effect on the environment. According to the results, MPs smaller than 1 mm in size could be removed by ultrafiltration treatment with a removal efficiency of 58.33%. Advanced methods like reverse osmosis and nanofiltration, however, did not produce sufficient outcomes.

Reverse osmosis

According to the study by [70] , the landfill leachate reverse osmosis concentrate (LLROC) underwent integrated treatment, which successfully raised biodegradability to BOD5/COD = 0.4 and removed 86% Al, 77% Zn, 84% Mn, 99% Mg, and 98% Si as well as 99.9% of colour, 90% COD, 90% sulphate, and 90% of nitrogen.

The study by [71]used a disc tube reverse osmosis (DTRO) treatment device to handle mature landfill leachate. Due to the DTRO, the effluent's electrical conductivity was reduced to 0.15–0.22 ms/cm, increased water recovery by >83%, and brought the level of carbonaceous and nitrogenous impurities to a standard level before it was discharged to streams, it was advantageous to the treatment system. Similar to saturated compounds, most of the macromolecular dissolved organic compounds were eliminated by the procedure; nonetheless, they might be harmful to the environment.

Using RO to treat leachate resulted in the removal of 98% of COD, 99% of total nitrogen, 99% of suspended particles, 94% of oil or grease, and 94% of colour and heavy metals, according to a study by [72].The system's newly integrated sand filter, which also contributes to extending the life of the RO, determines the quantity of leachate present. According to the report, obstacles to the RO treatment system include high energy consumption, a brief lifetime, and membrane maintenance.

Reverse osmosis (RO) was utilised in the study by [73] to treat landfill leachate. RO was previously used in saltwater desalination plants. The used RO ran for 27 months while using less electricity. This came to the conclusion that recycling and regeneration of membranes is an alternative to disposal in landfills.

Land treatment of Leachates from landfills

According to the study by [74], landfill liner systems are becoming more important for geo-environmental protection and also serve as a geochemical barrier to stop the movement of dangerous chemicals like heavy metals in waste leachate. The liner systems of landfill sites have tended to improve as a result of ongoing improvements in landfill technology. The investigation of the different pollutants' attenuation in leachate in liner systems is currently receiving more focus. The superior physical, chemical, and structural qualities of lateritic soil-bentonite mixes have drawn researchers' attention as a material for liner construction in tropical climates.

Because of their low permeability and sorption properties, as well as their ease of installation, the soil beneath landfills can be used as a protective barrier to stop the migration of contaminants, according to a study by [75]. The recognised natural attenuation ability of soil against chemical species in solution is mostly determined by its texture; those with a higher fine content are more reactive, while the clay fraction's clay-like particles draw circulating ions and facilitate their adsorption.

The study by [76] demonstrates how to effectively treat landfill leachate, which is thought to have better sorption characteristics of pollutants, using iron- and aluminum-rich laterite soil type as the filter media. In order to enhance the biological properties of laterite, biofiltering was activated by using compost as an enrichment media. The added compost can stimulate microbial activities, improving the filter performance. For the treatment of contaminated water, laterite has been utilised as an efficient filter medium. The removal of BOD, COD, phosphate, and nitrate from leachate is very successful when numerous processes, including ion exchange, surface adsorption, chemical precipitation, and biological processes, are used. It was noted that over the first 20 days, the removal efficiency of BOD, COD, phosphate, and nitrate fluctuated. Further biodegradation has improved the efficiency' stability. The microenvironment of the filter media may have changed as a result of the microbial population, which needed some time to adjust to the new environment. The removals for BOD (>90%), COD (>85%), and phosphate (>90%) increased when the filters (A, B, C, and D) stabilised. The progressive rise in nitrate removal (from 75 to 95%) may be the result of denitrification caused by the extra carbon that was added to the filter media. Fe removal efficiency was reported to be high (90–100%), whereas Mn, Cu, Ni, Cd, Zn, and Pb removal efficiency trends covered a wide range, demonstrating several metal sorption mechanisms.

3.3. Combination of physical, chemical, and biological treatment

According to studies, combining biological treatment with physical and chemical processes performed more well than employing just one treatment method alone. Reverse osmosis in conjunction with a revolving biological contactor effectively eliminated 99% of the chemical oxygen demand (COD), biological oxygen demand (BOD), and N-NH_4^+. Similar to reverse osmosis, activated sludge reverse osmosis treated 99-99.5% of COD and 99-99.8% of N-NH_4^+. Treatment of the whole suspended solid using membrane bioreactor or reverse osmosis with activated sludge both produced better results. A combination biological process and photo-Fenton process is used to achieve the high concentrations of the organic load effluent [77].

The COD and BOD, which were purified up to 98% met the standard before releasing into recipient water bodies. According to the research by [78] , a substitute for treating landfill leachate is a membrane bioreactor combined with Saccharomyces cerevisiae (MBRy), nanofiltration (NF), and Fenton. A different approach was also implemented that applies the MBRy-NF-Fenton process of treatment to the permeate from the MBRy and NF processes (MBRy-Fenton-NF). 85.5% of COD was eliminated using the Fenton procedure. Results from the NF treatment of MBRy permeate were superior to those from other treatments. The MBRy-Fenton's final COD concentration was discovered to be lower. For NF concentrate, the Fenton treatment procedure eliminated 87.24% of COD. The quantity of chemical reagents and membrane area needed was decreased by this procedure.

4. Conclusion

Before being released into the environment, landfill leachate must be managed and treated since it can have a negative influence on both human health and the ecosystem. Leachate comprises highly poisonous organic and inorganic chemicals. The treatment is done in accordance with its makeup. Physical, chemical, and biological treatments are frequently used in treatment; each has benefits and drawbacks. The removal of colour, turbidity, suspended particles, colloidal particles, and heavy metals by the coagulation and flocculation process showed great efficiency performance.

The ANAMMOX technique can be used to treat leachate with a high nitrogen content and extract nitrogen and ammonia from landfill leachate. Combining biological and physio-chemical treatments led to a greater reduction of pollutants for the leachate's successful removal of contaminants. To establish the proper treatment for the leachate, more study on landfill leachate management needs to be conducted. The leachate onsite solution is given a good low cost choice by the land treatment of the landfill leachate. For the correct construction of the leachate treatment, more research on landfill leachate treatment management must be done.

References

[1] Costa A M, Alfaia R G d S M, Campos J C. Landfill leachate treatment in brazil – an overview[J/OL]. Journal of Environmental Management, 2019, 232(November 2018): 110-116. DOI: 10.1016/j.jenvman.2018.11.006.

[2] Bisht T S, Kumar D, Alappat B J. Revised leachate pollution index (r-lpi): A tool to quantify the contamination potential of landfill leachate[J/OL]. Process Safety and Environmental Protection, 2022, 168: 1142-1154. DOI: 10.1016/j.psep.2022.10.052.

[3] Gao J, et al. The present status of landfill leachate treatment and its development trend from a technological point of view[J/OL]. Reviews in Environmental Science and Biotechnology, 2015, 14(1): 93-122. DOI: 10.1007/s11157-014-9349-z.

[4] Mojiri A, et al. Treatment of landfill leachate with different techniques: An overview[J/OL]. Journal of Water Reuse and Desalination, 2021, 11(1): 66-96. DOI: 10.2166/wrd.2020.079.

[5] Kjeldsen P, Barlaz M A, Rooker A P, et al. Present and long-term composition of msw landfill leachate: A review[J/OL]. Critical Reviews in Environmental Science and Technology, 2002, 32(4): 297-336. DOI: 10.1080/10643380290813462.

[6] Miao L, Yang G, Tao T, et al. Recent advances in nitrogen removal from landfill leachate using biological treatments – a review[J/OL]. Journal of Environmental Management, 2019, 235(January): 178-185. DOI: 10.1016/j.jenvman.2019.01.057.

[7] Wang K, Li L, Tan F, et al. Treatment of landfill leachate using activated sludge technology: A review[J/OL]. Archaea, 2018, 2018. DOI: 10.1155/2018/1039453.

[8] Anqi T, Zhang Z, Suhua H, et al. Review on landfill leachate treatment methods[J/OL]. IOP Conference Series: Earth and Environmental Science, 2020, 565(1). DOI: 10.1088/1755-1315/565/1/012038.

[9] Kurniawan T A, Lo W, Chan G, et al. Biological processes for treatment of landfill leachate[J/OL]. Journal of Environmental Monitoring, 2010, 12(11): 2032-2047. DOI: 10.1039/c0em00076k.

[10] Dutta A, Sarkar S. Sequencing batch reactor for wastewater treatment: Recent advances[J/OL]. Current Pollution Reports, 2015, 1(3): 177-190. DOI: 10.1007/s40726-015-0016-y.

[11] Prasad R S S, Balasubramanian A, Suresh B. Sequencing batch reactor as an efficient alternative to wastewater treatment-a model from pharmaceutical industries nature environment and pollution technology an international quarterly scientific journal[J]. Nature Environment and Pollution Technology, 2011, 10(2): 167-172.

[12] Wei Y, et al. Microbial analysis for the ammonium removal from landfill leachate in an aerobic granular sludge sequencing batch reactor[J/OL]. Bioresource Technology, 2021, 324(December 2020): 124639. DOI: 10.1016/j.biortech.2020.124639.

[13] Islam M, Xu Q, Yuan Q. Advanced biological sequential treatment of mature landfill leachate using aerobic activated sludge sbr and fungal bioreactor[J/OL]. Journal of Environmental Health Science and Engineering, 2020, 18(1): 285-295. DOI: 10.1007/s40201-020-00466-z.

[14] Tałałaj I A, Bartkowska I, Biedka P. Treatment of young and stabilized landfill leachate by integrated sequencing batch reactor (sbr) and reverse osmosis (ro) process[J/OL]. Environmental Nanotechnology, Monitoring & Management, 2021, 16(April). DOI: 10.1016/j.enmm.2021.100502.

[15] Jagaba A H, et al. Sequencing batch reactor technology for landfill leachate treatment: A state-of-the-art review[J/OL]. Journal of Environmental Management, 2021, 282(December 2020): 111946. DOI: 10.1016/j.jenvman.2021.111946.

[16] El-Fadel M, Hashisho J. A comparative examination of mbr and sbr performance for the treatment of high-strength landfill leachate[J/OL]. Journal of Air & Waste Management Association, 2014, 64(9): 1073-1084. DOI: 10.1080/10962247.2014.907840.

[17] Coppini E, Palli L, Fibbi D, et al. Long-term performance of a full-scale membrane plant for landfill leachate pretreatment: A case study[J/OL]. Membranes (Basel), 2018, 8(3): 4-13. DOI: 10.3390/membranes8030052.

[18] Witthayaphirom C, Chiemchaisri C, Chiemchaisri W, et al. Long-term removals of organic micro-pollutants in reactive media of horizontal subsurface flow constructed wetland treating landfill leachate[J/OL]. Bioresource Technology, 2020, 312: 123611. DOI: 10.1016/j.biortech.2020.123611.

[19] Liu J, Zhang P, Tian Z, et al. Pollutant removal from landfill leachate via two-stage anoxic/oxic combined membrane bioreactor: Insight in organic characteristics and predictive function analysis of nitrogen-removal bacteria[J/OL]. Bioresource Technology, 2020, 317(July): 124037. DOI: 10.1016/j.biortech.2020.124037.

[20] Sun F, et al. Effective biological nitrogen process and nitrous oxide emission characteristics for the treatment of landfill leachate with low carbon-to-nitrogen ratio[J/OL]. Journal of Cleaner Production, 2020, 268: 122289. DOI: 10.1016/j.jclepro.2020.122289.

[21] Mizyed A. Review on application of rotating biological contactor in removal of various pollutants from effluent[J]. Tech. Biochem., 2021, 2(1): 41-61.

[22] Song J, et al. A pilot-scale study on the treatment of landfill leachate by a composite biological system under low dissolved oxygen conditions: Performance and microbial community[J]. 2020, 296.

[23] Azreen I, Zahrim A Y. Overview of biologically digested leachate treatment using adsorption[J]. 2018, 0 (9789811081286).

[24] Singh V, Mittal A K. Toxicity and treatability of leachate: Application of uasb reactor for leachate treatment from okhla landfill, new delhi[J/OL]. Water Science & Technology, 2012, 65(10): 1887-1894. DOI: 10.2166/wst.2012.864.

[25] Liu J, Luo J, Zhou J, et al. Inhibitory effect of high-strength ammonia nitrogen on bio-treatment of landfill leachate using egsb reactor under mesophilic and atmospheric conditions[J/OL]. Bioresource Technology, 2012, 113: 239-243. DOI: 10.1016/j.biortech.2011.11.114.

[26] Luo J, Qian G, Liu J, et al. Anaerobic methanogenesis of fresh leachate from municipal solid waste: A brief review on current progress[J/OL]. Renewable and Sustainable Energy Reviews, 2015, 49: 21-28. DOI: 10.1016/j.rser.2015.04.053.

[27] Wiszniowski J, Robert D, Surmacz-Gorska J, et al. Landfill leachate treatment methods: A review[J/OL]. Environmental Chemistry Letters, 2006, 4(1): 51-61. DOI: 10.1007/s10311-005-0016-z.

[28] Mojiri A, Ohashi A, Ozaki N, et al. Integrated anammox-biochar in synthetic wastewater treatment: Performance and optimization by artificial neural network[J/OL]. Journal of Cleaner Production, 2020, 243: 118638. DOI: 10.1016/j.jclepro.2019.118638.

[29] Jiang H, et al. Efficient and advanced nitrogen removal from mature landfill leachate via combining nitritation and denitritation with anammox in a single sequencing batch biofilm reactor[J/OL]. Bioresource Technology, 2021, 333(April): 125138. DOI: 10.1016/j.biortech.2021.125138.

[30] Jiang H, Peng Y, Li X, et al. Advanced nitrogen removal from mature landfill leachate via partial nitrification-anammox biofilm reactor (pnabr) driven by high dissolved

oxygen (do): Protection mechanism of aerobic biofilm[J/OL]. Bioresource Technology, 2020, 306: 123119. DOI: 10.1016/j.biortech.2020.123119.

[31] Zhang F, Peng Y, Wang S, et al. Efficient step-feed partial nitrification, simultaneous anammox and denitrification (spnad) equipped with real-time control parameters treating raw mature landfill leachate[J/OL]. Journal of Hazardous Materials, 2019, 364: 163-172. DOI: 10.1016/j.jhazmat.2018.09.066.

[32] Bakhshoodeh R, et al. Constructed wetlands for landfill leachate treatment: A review[J/OL]. Ecological Engineering, 2020, 146 (December 2019). DOI: 10.1016/j.ecoleng.2020.105725.

[33] Mojiri A, Ziyang L, Tajuddin R M, et al. Co-treatment of landfill leachate and municipal wastewater using the zeliac/zeolite constructed wetland system[J/OL]. Journal of Environmental Management, 2016, 166: 124-130. DOI: 10.1016/j.jenvman.2015.10.020.

[34] Dan D A, Fujii D, Soda S, et al. Removal of phenol, bisphenol a, and 4-tert-butylphenol from synthetic landfill leachate by vertical flow constructed wetlands[J/OL]. Science of the Total Environment, 2017, 578: 566-576. DOI: 10.1016/j.scitotenv.2016.10.232.

[35] Zhuang L L, Yang T, Zhang J, et al. The configuration, purification effect and mechanism of intensified constructed wetland for wastewater treatment from the aspect of nitrogen removal: A review[J/OL]. Bioresource Technology, 2019, 293(August). DOI: 10.1016/j.biortech.2019.122086.

[36] Kumar P, Choudhary A K. Constructed wetlands-a sustainable solution for landfill leachate treatment[J]. International Journal of Latest Technology in Engineering, 2018, VII(June).

[37] Ghaffariraad M, Ghanbarzadeh Lak M. Landfill leachate treatment through coagulation-flocculation with lime and biosorption by walnut-shell[J/OL]. Environmental Management, 2021, 68(2): 226-239. DOI: 10.1007/s00267-021-01489-4.

[38] Chaouki Z, et al. Use of coagulation-flocculation process for the treatment of the landfill leachates of casablanca city (morocco)[J]. Journal of Materials and Environmental Science, 2017, 8(8): 2781-2791.

[39] Smaoui Y, Bouzid J, Sayadi S. Combination of air stripping and biological processes for landfill leachate treatment[J/OL]. Environmental Engineering Research, 2020, 25(1): 80-87. DOI: 10.4491/eer.2018.268.

[40] Leite V D, Paredes J M R, de Sousa T A T, et al. Ammoniacal nitrogen stripping from landfill leachate at open horizontal flow reactors[J/OL]. Water Environment Research, 2018, 90(5): 387-394. DOI: 10.2175/106143017x15131012152942.

[41] Tałałaj I A, Biedka P, Bartkowska I. Treatment of landfill leachates with biological pretreatments and reverse osmosis[J/OL]. Environmental Chemistry Letters, 2019, 17(3): 1177-1193. DOI: 10.1007/s10311-019-00860-6.

[42] Erabee I K, et al. Adsorptive treatment of landfill leachate using activated carbon modified with three different methods[J/OL]. KSCE Journal of Civil Engineering, 2018, 22(4): 1083-1095. DOI: 10.1007/s12205-017-1430-z.

[43] Reshadi M A M, Bazargan A, McKay G. A review of the application of adsorbents for landfill leachate treatment: Focus on magnetic adsorption[J/OL]. Science of the Total Environment, 2020, 731: 138863. DOI: 10.1016/j.scitotenv.2020.138863.

[44] Zielińska M, Kulikowska D, Stańczak M. Adsorption – membrane process for treatment of stabilized municipal landfill leachate[J/OL]. Waste Management, 2020, 114: 174-182. DOI: 10.1016/j.wasman.2020.07.011.

[45] Abuabdou S M A, Yew Y H, Ahmad W, et al. Treatment of tropical stabilized landfill leachate by adsorption using powdered activated carbon: Isothermal and kinetic studies[J/OL]. IOP Conference Series: Earth and Environmental Science, 2021, 799(1). DOI: 10.1088/1755-1315/799/1/012032.

[46] Pedro L S, Novelo R M, Nunez E H, et al. Selection of the activated carbon type for the treatment of landfill leachate by fenton-adsorption process[J]. Molecules, 2020: 16.

[47] Scandelai A P J, Zotesso J P, Jegatheesan V, et al. Intensification of supercritical water oxidation (scwo) process for landfill leachate treatment through ion exchange with zeolite[J/OL]. Waste Management, 2020, 101: 259-267. DOI: 10.1016/j.wasman.2019.10.005.

[48] Bagastyo A Y, Sari P P I, Direstiyani L C. Effect of chloride ions on the simultaneous electrodialysis and electrochemical oxidation of mature landfill leachate[J/OL]. Environmental Science and Pollution Research, 2021, 28(45): 63646-63660. DOI: 10.1007/s11356-020-11519-z.

[49] Bai Z, et al. Study on anti-scaling of landfill leachate treated by evaporation method[J/OL]. Water Science and Technology, 2021, 84(1): 122-134. DOI: 10.2166/wst.2021.210.

[50] Vollprecht D, Frühauf S, Stocker K, et al. Ammonium sorption from landfill leachates using natural and modified zeolites: Pre-tests for a novel application of the ion exchanger loop stripping process[J/OL]. Minerals, 2019, 9(8). DOI: 10.3390/min9080471.

[51] Mohan S, Gokul D. Treatment of leachate from open dumpsite of municipal solid waste by ozone based advanced oxidation process[J/OL]. Ozone: Science & Engineering, 2022, 44(3): 250-264. DOI: 10.1080/01919512.2021.1919053.

[52] Varank G, Yazici Guvenc S, Dincer K, et al. Concentrated leachate treatment by electro-fenton and electro-persulfate processes using central composite design[J/OL]. International Journal of Environmental Research, 2020, 14(4): 439-461. DOI: 10.1007/s41742-020-00269-y.

[53] Mohan S, Mamane H, Avisar D, et al. Treatment of diethyl phthalate leached from plastic products in municipal solid waste using an ozone-based advanced oxidation process[J/OL]. Materials, 2019, 12(24). DOI: 10.3390/ma12244119.

[54] Asaithambi P, Govindarajan R, Yesuf M B, et al. Removal of color, cod and determination of power consumption from landfill leachate wastewater using an electrochemical advanced oxidation processes[J/OL]. Separation and Purification Technology, 2020, 233: 115935. DOI: 10.1016/j.seppur.2019.115935.

[55] Singa P K, Isa M H, Lim J W, et al. Photo-fenton process for removal of polycyclic aromatic hydrocarbons from hazardous waste landfill leachate[J/OL]. International Journal of Environmental Science and Technology, 2021, 18(11): 3515-3526. DOI: 10.1007/s13762-020-03010-6.

[56] J. U, T. B, S. S, et al. A feasibility study on optimization of combined advanced oxidation processes for municipal solid waste leachate treatment[J/OL]. Process Safety and Environmental Protection, 2020, 143: 212-221. DOI: 10.1016/j.psep.2020.06.040.

[57] Viegas C, Nobre C, Mota A, et al. A circular approach for landfill leachate treatment: Chemical precipitation with biomass ash followed by bioremediation through microalgae[J/OL]. Journal of Environmental Chemical Engineering, 2021, 9(3). DOI: 10.1016/j.jece.2021.105187.

[58] Barbosa Segundo I D, Silva T F C V, Moreira F C, et al. Sulphur compounds removal from an industrial landfill leachate by catalytic oxidation and chemical precipitation: From a hazardous effluent to a value-added product[J/OL]. Science of the Total Environment, 2019, 655: 1249-1260. DOI: 10.1016/j.scitotenv.2018.11.274.

[59] Martínez-Cruz A, et al. An eco-innovative solution for reuse of leachate chemical precipitation sludge: Application to sanitary landfill coverage[J/OL]. Ecological Engineering and Environmental Technology, 2021, 22(2): 52-58. DOI: 10.12912/27197050/133329.

[60] Ates H, Argun M E. Removal of pahs from leachate using a combination of chemical precipitation and fenton and ozone oxidation[J/OL]. Water Science and Technology, 2018, 78(5): 1064-1070. DOI: 10.2166/wst.2018.378.

[61] Ramaswami S, Behrendt J, Otterpohl R. Comparison of nf-ro

and ro-nf for the treatment of mature landfill leachates: A guide for landfill operators[J/OL]. Membranes (Basel), 2018, 8(2). DOI: 10.3390/membranes8020017.

[62] Dabaghian Z, Peyravi M, Jahanshahi M, et al. Potential of advanced nano-structured membranes for landfill leachate treatment: A review[J/OL]. ChemBioEng Rev., 2018, 5(2): 119-138. DOI: 10.1002/cben.201600020.

[63] Siyal M I, Lee C K, Park C, et al. A review of membrane development in membrane distillation for emulsified industrial or shale gas wastewater treatments with feed containing hybrid impurities[J/OL]. J. Environ. Manage., 2019, 243: 45-66. DOI: 10.1016/j.jenvman.2019.04.105.

[64] T. Istirokhatun D A A, Oktiawan W. Removal of refractory compounds from[J]. Jurnal Teknologi, 2018, 2: 1-8.

[65] de Almeida R, et al. Nanofiltration applied to the landfill leachate treatment and preliminary cost estimation[J/OL]. Waste Manag. Res., 2020, 38(10): 1119-1128. DOI: 10.1177/0734242X20933333.

[66] de Almeida R, Moraes Costa A, de Almeida Oroski F, et al. Evaluation of coagulation–flocculation and nanofiltration processes in landfill leachate treatment[J/OL]. J. Environ. Sci. Heal. - Part A Toxic/Hazardous Subst. Environ. Eng., 2019, 54(11): 1091-1098. DOI: 10.1080/10934529.2019.1631093.

[67] Esfahani A R, Zhai L, Sadmani A H M A. Removing heavy metals from landfill leachate using electrospun polyelectrolyte fiber mat-laminated ultrafiltration membrane[J/OL]. J. Environ. Chem. Eng., 2021, 9(4): 105355. DOI: 10.1016/j.jece.2021.105355.

[68] Zait M, et al. Performance of three ultrafiltration ceramic membranes in reducing polluting load of landfill leachate[J/OL]. Desalin. Water Treat., 2021, 240: 33-42. DOI: 10.5004/dwt.2021.27612.

[69] Zhang Z, Su Y, Zhu J, et al. Distribution and removal characteristics of microplastics in different processes of the leachate treatment system[J/OL]. Waste Manag., 2021, 120: 240-247. DOI: 10.1016/j.wasman.2020.11.025.

[70] Tejera J, et al. Assessing an integral treatment for landfill leachate reverse osmosis concentrate[J/OL]. Catalysts, 2020, 10(12): 1-17. DOI: 10.3390/catal10121389.

[71] Wu C, Li Q. Characteristics of organic matter removed from highly saline mature landfill leachate by an emergency disk tube-reverse osmosis treatment system[J/OL]. Chemosphere, 2021, 263: 128347. DOI: 10.1016/j.chemosphere.2020.128347.

[72] Topal A D, Atasoy A D. Reverse osmosis treatment system for landfill leachate: Operation conditions, advantages and challenges[J/OL]. Environ. Res. Technol., 2022, 5(2): 119-127. DOI: 10.35208/ert.1027553.

[73] García-Pacheco R, et al. Landfill leachate treatment by using second-hand reverse osmosis membranes: Long-term case study in a full-scale operating facility[J/OL]. Membranes (Basel), 2022, 12(11): 1170. DOI: 10.3390/membranes12111170.

[74] Amadi A, Odedede O. Attenuation of contaminants in landfill leachate by lateritic soil enhanced with bentonite[J/OL]. Geomech. Geoengin., 2019, 00(00): 1-11. DOI: 10.1080/17486025.2019.1670872.

[75] Gonçalves F, Correa C Z, Lopes D D, et al. Monitoring of the process of waste landfill leachate diffusion in clay and sandy soil[J/OL]. Environ. Monit. Assess., 2019, 191(9). DOI: 10.1007/s10661-019-7720-9.

[76] Nayanthika I V K, Jayawardana D T, Bandara N J G J, et al. Effective use of iron-aluminum rich laterite based soil mixture for treatment of landfill leachate[J/OL]. Waste Manag., 2018, 74: 347-361. DOI: 10.1016/j.wasman.2018.01.013.

[77] Colombo A, Módenes A N, Góes Trigueros D E, et al. Treatment of sanitary landfill leachate by the combination of photo-fenton and biological processes[J/OL]. J. Clean. Prod., 2019, 214: 145-153. DOI: 10.1016/j.jclepro.2018.12.310.

[78] Brasil Y L, Moreira V R, Lebron Y A R, et al. Combining yeast mbr, fenton and nanofiltration for landfill leachate reclamation[J/OL]. Waste Manag., 2021, 132(June): 105-114. DOI: 10.1016/j.wasman.2021.07.027.